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(54) **Heat regenerators**

(57) A rotary heat regenerator having a matrix formed of synthetic plastics material in which the dimensions of the matrix conforms to certain dimensional parameters. In one embodiment, the matrix strip (10.30) is provided with transverse embossments that have a length less than that of the strip width to allow winding tension to be applied to the strip without affecting the dimensions of the embossments. The design parameters permitted by the use of plastics allows the manufacture of matrix wheels with minimum thickness which minimizes circumferential leakage.

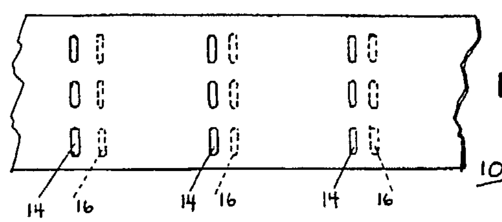


FIG. 1

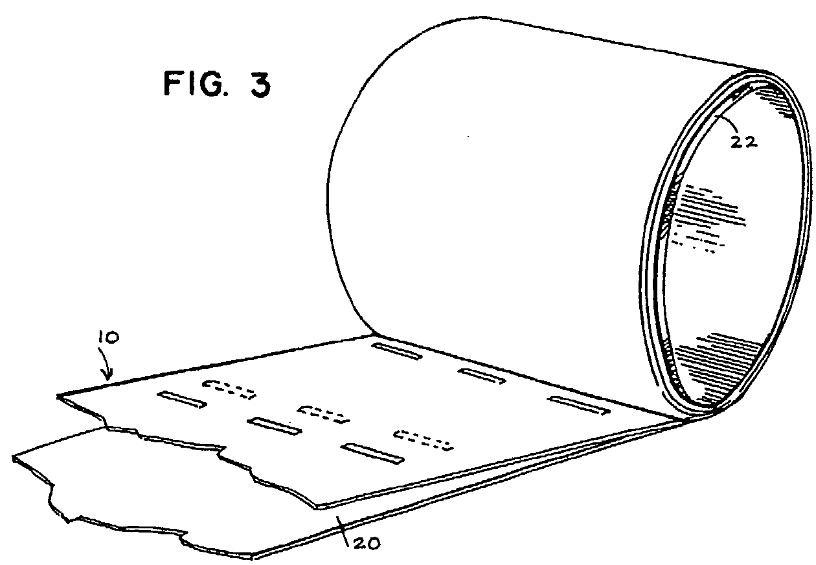


FIG. 3

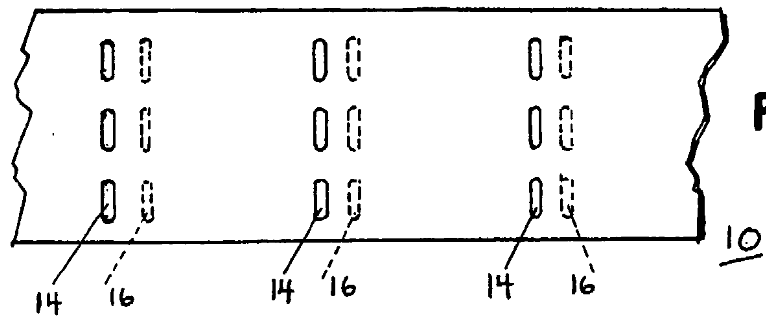


FIG. 1

FIG. 2

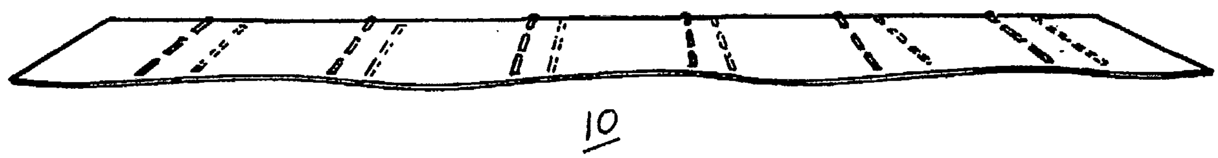
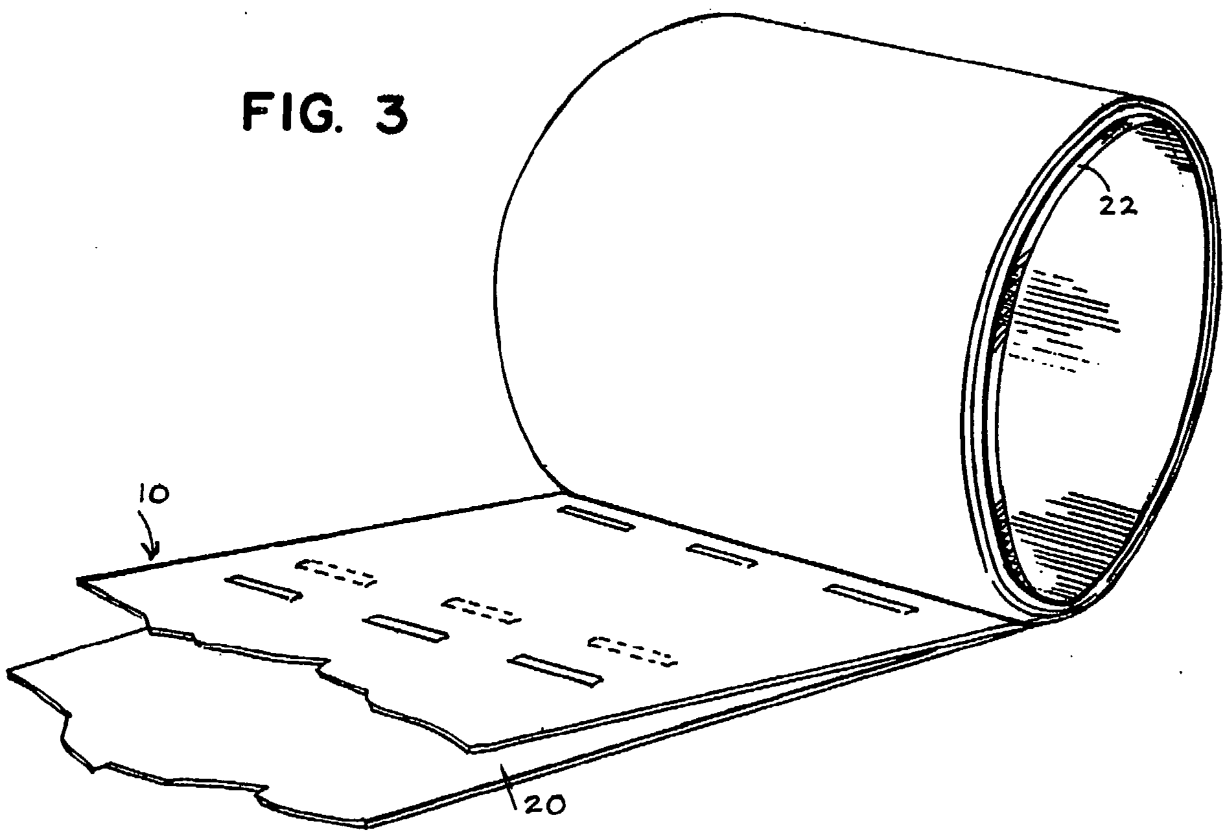


FIG. 3



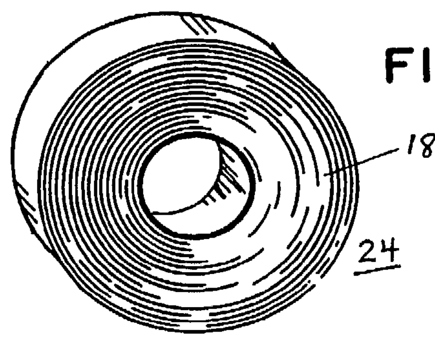


FIG. 4

FIG. 5

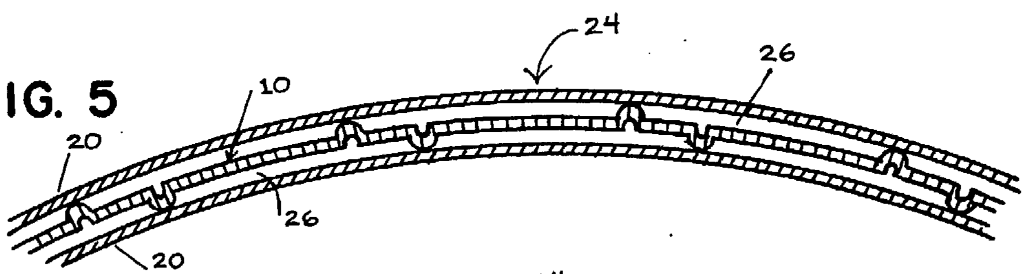


FIG. 6

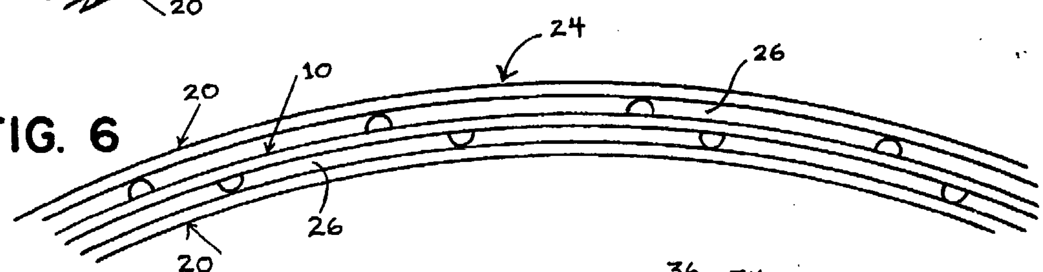


FIG. 7

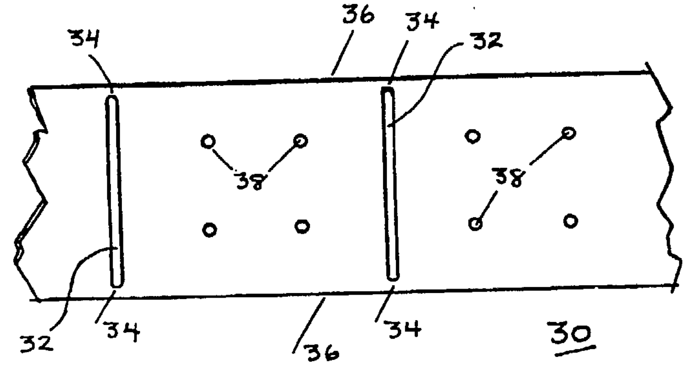


FIG. 8

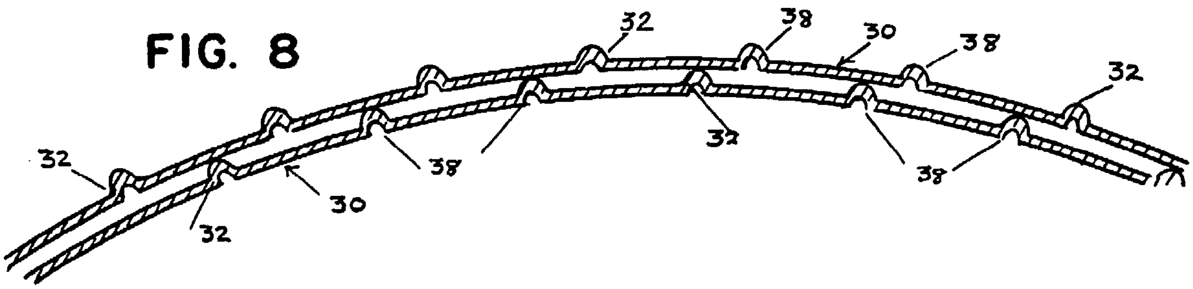


FIG. 9

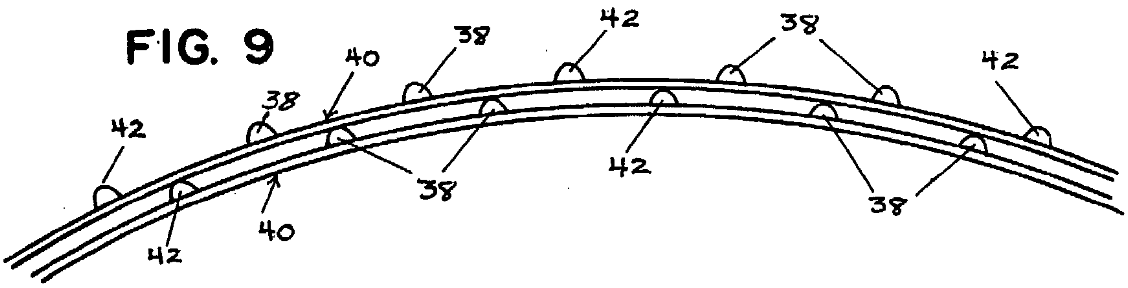
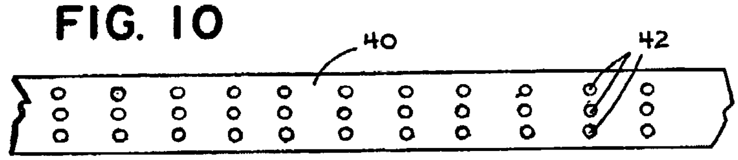


FIG. 10



SPECIFICATION
Heat regenerators

The invention relates to heat regenerators.

In the manufacture of compact rotary heat regenerators, it has been considered desirable to form the regenerator matrix of a material having a relatively low heat conductivity to minimize heat transfer between the opposite faces of the regenerator. However it has also been considered essential that the matrix material should have sufficient heat conductivity to allow heat from the gas flowing through the matrix to travel into the body of the matrix layers from the surface thereof, since otherwise the matrix would have insufficient available heat storage capacity. The matrix material should also have a specific heat high enough to provide adequate heat storage capacity.

Stainless steel is often used as the matrix material in rotary regenerators, in the form of a strip wound around a central hub. In addition to excellent corrosion resistance, stainless steel has a heat conductivity which is lower than other commonly available metals. However, its cost is high, so that when used as a matrix material in low capacity low temperature rotary regenerators such as might be used for residential ventilation, the cost of the resulting device is so high that it is unmarketable for high volume applications. Also, the design parameters for a stainless steel wheel of low capacity (under 500 cubic feet per minute) are such that the resulting wheel is so thin in its transverse dimension that the heat conductance between its faces becomes substantial, thereby reducing the efficiency of the regenerator. To increase the width of the wheel to reduce the heat flow between faces would unduly increase the manufacturing cost, which is already too high to be commercially acceptable, and can also increase the circumferential gas leakage in the matrix.

The use of a material with a conductivity as low as that of synthetic organic plastics as a matrix material has been generally considered to be impractical, since its conductivity is only about .05 to .1 BTU/hr-ft./deg.F, compared to 12 BTU/hr-ft./deg.F for stainless steel. In other words plastics materials have a conductivity only about 1/120 to 1/240 that of stainless steel. Although this low conductivity would prevent any substantial conduction between the opposite faces of the matrix, it would presumably be just as effective in preventing conduction from the surface of the plastics into the body thereof, and therefore the plastics material would provide no effective heat storage capacity. Also, the specific heat of plastics material, on a volume basis, is only about half that of stainless steel.

The coils of a regenerator matrix must have spacing means to create gas passages, and the coils must be flat in a transverse direction, and uniformly spaced apart so that the gas passages are of uniform height throughout their length for greatest efficiency. For compactness and economy, the gas passages should have a small hydraulic diameter and a large aspect ratio, that is, ratio of width to height.

It has been found that many types of commercially available plastics films in strip form do not have a flatness which is adequate to provide gas passages of uniform size, since the sheet from which such strips are formed are not accurately flat, apparently due to residual stresses from extrusion and from the slitting process. Hence strips formed from such sheets would have an edge with a wavy configuration. The forming of transverse embossments in the strip as spacers to provide gas passages and to prevent circumferential gas leakage in the regenerator wheel, in the manner known and used in prior devices in which the matrix strip is stainless steel does nothing to alleviate this problem, since transverse embossments formed in a plastics strip tend to deform to a lesser height when tension is applied to the strip during winding onto a hub to form the regenerator matrix. This causes a reduction in the thickness of the gas passages and also increases the effect of non-flat strip portions and wavy edges on the gas passage dimensions. From a manufacturing stand-point, it would be easiest merely to form dimples in the strip, such dimples projecting from either one surface or both surfaces. This structure provides a desirable high aspect ratio, but unfortunately allows appreciable circumferential gas leakage, reducing the air exchange effectiveness of the regenerator.

The invention accordingly provides a counterflow type heat regenerator matrix comprising layers with spacing means forming gas passages through the matrix between layers, the layers comprising synthetic plastics layers in film form.

The invention also provides a rotary counterflow heat regenerator matrix comprising a wound strip with spacing means to form gas passages, the strip comprising plastics strip.

The invention also provides a counterflow heat regenerator matrix, formed of a strip of material wound around a hub, the strip having embossments formed at longitudinally spaced positions on the strip, the outer ends of the embossments at each location terminating in spaced relation to the side edges of the strip, whereby a continuous portion of the strip along the side edges is un-embossed.

A regenerator with a matrix in accordance with this invention can have an efficiency equal to or greater than a regenerator of identical size having a matrix formed of a strip of stainless steel. A matrix embodying the invention may be provided with accurately dimensioned air or gas passages and adequate resistance to circumferential air or gas leakage, by providing the strip with transverse embossments which have a total length less than the width of the strip, and which preferably do not extend to the edges of the strip. The embossment configuration at any longitudinal position on the strip may be a single embossment that extends

across the entire strip, except for a small predetermined distance at each edge of the strip, or may be two or more separate aligned embossments with unembossed portions at the edges and at one or more intermediate positions. The presence of the unembossed portions promote retention of strip flatness and allows winding tension to be applied to the strip without changing the vertical dimension of the embossment, yet an embossment extending substantially all of the way across the strip prevents any substantial circumferential gas leakage in the matrix.

The design parameters resulting from the use of plastics film as the matrix material allow the construction of a regenerator wheel with much less thickness than has been possible when metal is used as the matrix material, yet with an effectiveness as great or greater than that of a metal wheel several times the thickness. The use of a thinner matrix not only requires less material, but also provides reduced circumferential leakage past the transverse seals, to an extent such that in many applications, a simple dimple spacing means may be used without excessive leakage.

Even strips with a slightly wavy edge may be formed into a satisfactory matrix, since when such a strip is wound into spiral form around a central hub, the bending of the strip causes the non-flat areas of the strip to become axially flat and the wavy edge portions to become accurately concentric, so that the spacing between the strip layers is uniform. The strip may be formed of any suitable plastics material which has an adequate modulus of elasticity, for example, about 150,000 psi., and adequate resistance to deformation at the temperature at which the regenerator is to be operated.

Where:

Ks is the heat conductivity of the plastics material of the strip of the matrix;
Kg is the heat conductivity of the gas to be passed through the matrix;
S is the spacing between the layers of the strip;
t is the thickness of the strip; and
L is the length of gas passages,

it is preferred that the parameters

$$\frac{KsS}{Kgt}, \quad \frac{KsS}{t}, \quad \frac{KgL^2}{KsSt} \quad \text{and} \quad \frac{L^2}{KsSt}$$

have the following values:

$\frac{KsS}{Kgt}$ — less than 100 and preferably between about 10 and 100;

$\frac{KsS}{t}$ — about 1.4 BTU/hr.-ft.deg.F or greater and preferably between about 0.14 and 1.4 BTU/hr.-ft.deg.F;

$\frac{KgL^2}{KgSt}$ — about 500 or more; and

$\frac{L^2}{KsSt}$ — about 7 hr.-ft.deg.F./BTU or more.

The invention is further described below by way of example with reference to the following description and the accompanying drawings, in which:

Figure 1 is a plan view of a strip of plastics material embossed for use as the matrix of a rotary heat regenerator;

Figure 2 is an edge view of the strip of Figure 1;

Figure 3 is a perspective view of the strip of Figure 1 being wound onto a hub, together with an unembossed strip to form a regenerator matrix;

Figure 4 is a perspective view of a completed regenerator matrix using the strip of Figure 1;

Figure 5 is a sectional view on a larger scale of a portion of the regenerator matrix of Figure 4;

Figure 6 is a side view on the larger scale of a portion of the regenerator matrix of Figure 4;

Figure 7 is a plan view of a modified form of strip for use in a regenerator matrix;

Figure 8 is a sectional view on a larger scale of a portion of a regenerator matrix manufactured using the strip of Figure 7;

Figure 9 is a side view on the larger scale of a face of a regenerator matrix manufactured using a narrower strip as shown in Figure 10; and

Figure 10 is a plan view of the strip of plastics material used in manufacturing the matrix of Figure 9.

Figures 1 and 2 of the drawings illustrate a strip 10 of plastics sheet or film for use as a spiral winding of a rotary heat regenerator intended for use as a low capacity residential ventilation unit

The strip 10 may be composed of any synthetic organic plastics which is sufficiently flexible to be wound into a spiral of the desired radius, yet has sufficient rigidity for the edges of the strip layers to maintain their proper relation to each other in the spiral and not be deflected by the gas flow through the matrix. Examples of plastics suitable for such use (assuming the gas temperature is below their heat distortion temperature) include but are not limited to polystyrene, polycarbonate, polyvinylchloride, and polyethylene terephthalate polyester resins.

In the manufacture of rotary heat regenerators by spirally winding a strip of material around a central hub, it is necessary to provide spacing means between the strip layers to create gas passages. Various spacing means have been used with metal strips, including a plurality of dimples formed in the strip, or a series of transverse folds or ridges spaced apart an appropriate distance. Some important considerations in the design of such regenerators are the desirability of small hydraulic diameters and high aspect ratio gas passages, and of minimizing leakage around radial seals resulting from circumferential gas flow through the matrix. Although a strip with a plurality of dimples is easy to manufacture, and

provides a high aspect ratio, such strips as previously known provide little resistance to circumferential gas flow, which reduces the overall air transfer effectiveness of the regenerator.

As previously stated, the use of transverse bends or embossments formed in the strip to create spacers in the manner previously used in metal strips is not acceptable for plastics strips, since tension applied to the strip during winding tends to cause the bends or embossments to flatten, changing the dimension of the gas passage, and imparting a wavy configuration to the strip.

Therefore, as shown in Figures 1 and 2, the strip 10 has been provided with a series of embossments 14 and 16 which project from opposite sides of the strip a predetermined distance as will appear hereinafter. The embossments 14 and 16 are positioned in rows each of three short embossments aligned with each other across the width of the strip, with the embossments spaced from each other and with the outer ends of the outermost embossments spaced from the side edges of the strip, for a purpose to appear hereinafter.

As shown in Figures 3—6, a regenerator matrix 18 may be manufactured from the strip by winding superimposed layers of the embossed stip 10 and an unembossed strip 20 having a hub 22 to form a regenerator wheel 24 having air passages 26 formed between the embossed strip and the unembossed strip.

In the regenerator matrix made of the strip 10, the gas passage height is determined by the height of the embossments 14 and 16 and the width is determined by the longitudinal spacing between the embossments. In a typical case, the embossments will be formed to have a height of about .03 inches or less, with a spacing between embossments of at least .6 inches, or at least about 20 times the height.

The provision of the elongate embossments, in addition to creating gas passages, also prevents any substantial circumferential gas leakage in the matrix.

Since the embossments do not extend across the entire width of the strip, but are positioned so as to provide flat unembossed portions at each side edge of the strip and at intermediate portions, the winding tension applied to the strip does not pass through the embossments, but is transmitted through the unembossed portions, so that the height of the embossments is not affected by the winding operation.

Although Figures 1 and 2 shows embossments provided on both sides of the strip, it will be understood that the strip may be provided with embossments on only one side if desired.

Figures 7 and 8 show a modified form of strip 30 for use in manufacturing a rotary heat regenerator, in which single elongate embossments 32 are provided at spaced portions along the strip, the embossments 32 being shorter than the width of the strip so as to leave unembossed portions 34 between the ends of the embossments and the side edges 36 of the strip.

In either embodiment of the invention, the elongate embossments may be spaced apart along the length of the strip a distance such that the aspect ratio is as high as desired, and other embossments in the form of dimples 38 may be provided in the strip between the elongate embossments. When the strip is wound into a spiral, the dimples 38, which preferably have the same height as the elongate embossments, maintain the strip layers at a uniform spacing between the elongate embossments, and therefore impart a uniform thickness to the air passages throughout their entire width which serves to increase the efficiency of the matrix, by maintaining substantially uniform gas velocity distribution throughout the matrix.

In the embodiment of the invention illustrated in Figures 9 and 10, a strip 40 has been provided only with dimples 42, for a reason to be described hereinafter.

As herein shown, although the strip, before winding, may have an undesirable amount of warping and edge undulations, it has been unexpectedly found that when the strip is wound into a spiral, the warping and the undulations disappear, and the resulting spiral strip has acceptable flatness in the direction of its width, and the undulant shape of the edges of the strip becomes substantially concentric layers spaced apart a substantially uniform distance.

To compare the performance of a rotary regenerator matrix formed of plastics material with a regenerator matrix formed of stainless steel, the following experiment was conducted.

A low capacity (50 cu.ft./minute) regenerator matrix was constructed by winding a stainless steel strip having a width of 1.5 inches and a thickness of .003 inches onto a hub having a diameter of 1.75 inches to provide an overall matrix diameter of 5.2 inches and an open flow area of 15.5 square inches. Strip projections were provided to create gas passages of about .015 inches between the strip layers.

A second regenerator matrix was constructed in the same manner by using a strip of Mylar having a width of 1.5 and with a thickness of .007 inches, with projections on the strip sized to provide gas passages about 0.15 inches thick. The plastics strip was wound around a hub of the same diameter as that used with the stainless steel strip, to a matrix diameter of 5.75 inches which provided the same open flow area as that of the stainless steel matrix, 15.5 square inches.

The matrices were then placed in a suitable housing with blowers and heaters to force air of one temperature through the matrix in one direction through one half of the matrix, and air of another temperature through the other half of the matrix in the other direction.

In the case of the stainless steel matrix, simulated indoor air at 67.6 degrees F achieved a temperature of 82.3 degrees F in passing through the matrix, and simulated dry outdoor air at 88.6

degrees F was reduced to a temperature of 72.0 degrees F. The efficiency of the outgoing section was therefore 70%, and the efficiency of the incoming section was 79%. Since the flow volume in each direction were substantially equal, the overall efficiency was 74.5%.

In the case of the regenerator matrix formed of the plastics strip, simulated air at 69.0 degrees F was discharged at 103.4 degrees F, and dry simulated outdoor air at 120.5 degrees F was received indoors at 74.4 degrees F, giving an outgoing efficiency of 67%, an incoming efficiency of 89%, and an overall efficiency of 78%.

This test demonstrates that a properly designed regenerator using a matrix of plastics can perform as well as, or better than, a properly design matrix of stainless steel which is operating near the threshold of performance loss due to heat conductivity through the matrix between the hot and cold faces resulting from a design which provides a minimum amount of material in the matrix. Since the cost of the plastics material in the matrix is about 10% of the cost of the stainless steel, it is apparent that the use of plastics is also commercially desirable, and can allow the manufacture of a commercially acceptable device in many applications where stainless steel would not.

As it has not been recognized in the art that a regenerator matrix formed of plastics is capable of transferring heat as effectively as a metal matrix, the following theoretical examination (by which the invention is not to be limited) has been made of reasons for this surprising result.

Apparently the greatest barrier to heat flow from the air or other gas to the body of the strip is not the strip conductivity, but the effective conductivity of the film of air or gas on the surface of the strip. If the thermal conductance of the strip is high compared to the conductance of the gas film, then the amount of heat transferred is controlled almost entirely by the gas conductance and little or not at all by the conductance of the strip material. If the conductance from the surface of the strip to its interior is at least 10 times greater than the conductance from the gas to the surface of the strip, then an effective matrix can be constructed from the material in question with no performance penalty. For the small high aspect ratio passages used in regenerators as described herein, a dimensionless parameter can be created which expresses the ratio of strip conductance to gas film conductance. This parameter is

$$\frac{KsS}{Kgt}$$

where Ks is the conductivity of the strip material, Kg is the conductivity of the gas passing through the matrix, S is the spacing between the matrix layers, and t is the thickness of the strip forming the matrix.

At room temperature the thermal conductances of air, stainless steel, and plastics in BTU/hr-ft.deg.F are respectively, .0145, 12, and .1. Therefore the dimensionless number resulting from the above formula for plastics, assuming a strip thickness of .007 inches and a strip spacing of .015 inches, is 14.8. This provides a theoretical reason for the excellent effectiveness of the plastics matrix, since in spite of the low conducitivy of the plastics material, the conductance of the plastics strip, with the geometry given, is still 14.8 times the effective conductance through the gas film to the plastics surface.

The heat transfer conductance figure for stainless steel, assuming a strip .003 inches thick (the thinner strip being practical when stainless steel is used) and with the same strip spacing is 4100. This high number indicates that the conductivity of the stainless steel is many times greater than is needed to make an effective regenerator matrix. In fact, the excess conductivity of stainless steel over the conductivity needed is often a detriment to the manufacture of an efficient low capacity heat regenerator because of the high rate of conduction between the regenerator faces. In order for a rotary regenerator matrix to operate at a high efficiency of heat transfer, it is necessary for the matrix material at the hot face to operate at a temperature near that of the incoming hot gas, and the matrix material near the cold face to operate near the temperature of the entering cold gas. In other words, a substantial temperature gradient must exist across the thickness of the wheel to achieve a highly efficient heat transfer. When the wheel thickness required is very small (due to the use of gas passages with a small hydraulic diameter) and metal is used for the matrix, then there will be excessive heat conduction through the matrix between the faces thereof, and the necessary temperature gradient between the hot and cold faces will not develop. To avoid this problem, in the design of a matrix wheel, the above factors (Ks, Kg, S and t) and also the wheel thickness L must be taken into account.

A dimensionless number that expresses the relative effectiveness in preventing heat flow between opposite faces of a matrix wheel is given by a heat flow resistance parameter

$$\frac{KgL^2}{KsSt}$$

From heat transfer theory, it can be shown that a reduction in effectiveness of a matrix due to heat conduction between the faces will be avoided when this parameter is about 50 or greater.

Assuming that L, the wheel thickness, is 1.5 inches, the heat flow resistance number given by this parameter for stainless steel with a strip thickness of .003 inches and a spacing of .015 between the strip layers is 60. It has been experimentally determined by the above example that a matrix made of stainless steel and having

the above dimensions is adequate but not exceptional in efficiency for a small capacity regenerator, thus confirming the fact that the heat flow resistance parameter of 50 should be considered as an absolute minimum.

However the high cost of stainless steel makes its use in small regenerators for residential use commercially impractical.

For a regenerator made of plastics film with a thickness of .007 inches, the heat flow resistance number given by the above parameter is 3100, indicating that there will be no problem with performance degradation in a plastics regenerator due to heat transfer between the matrix faces.

In the interest of reducing to a minimum the amount of material in the wheel, it may be desirable to use smaller spacing between the strip layers, which allows the construction of a wheel with a lesser thickness, yet having the same heat transfer effectiveness and the same pressure drop.

For example, a wheel may be constructed of plastics material of the same composition as in the above example, but with a strip spacing of .0075 inches and a strip thickness of .005 inches, in which case the wheel width L need be only .375 inches for the same heat transfer effectiveness and pressure drop through the wheel. Such a wheel will provide a

$$\frac{KsS}{Kgt}$$

value of 10 and a

$$\frac{KgL^2}{KsSt}$$

value of 544.

A heat regenerator wheel with such an unusually narrow width has the additional advantage of having reduced circumferential gas leakage in the matrix, the leakage path being so reduced that for many applications the spacing means between the layers can be merely a plurality of dimples rather than the transverse embossments described herein, without appreciable loss of air exchange effectiveness.

Thus it has been discovered that the low heat conductivity of plastics, rather than being a detriment, is actually unexpectedly advantageous in the manufacture of compact low capacity heat regenerators, in that the low conductivity of the plastics material prevents any appreciable loss of effectiveness due to heat conduction between the matrix faces, even in extremely thin matrix wheels. This fact, and the design dimensions permitted by the use of plastics strip allows the manufacture of matrix wheels with a minimum thickness, minimum amount of matrix material, and minimum circumferential leakage, yet the low conductance of the plastics matrix does not adversely affect the performance of the regenerator, since the conductance of the plastics is so much greater than the conductance of the gas to matrix surface.

Claims

1. A counterflow type heat regenerator matrix comprising layers with spacing means forming gas passages through the matrix between layers, the layers comprising synthetic plastics layers in film form.

2. A rotary counterflow heat regenerator matrix comprising a wound strip with spacing means to form gas passages, the strip comprising plastics strip.

3. A matrix as claimed in claim 2 wherein the parameter

$$\frac{KsS}{Kgt}$$

is less than about 100, where:

Ks is the heat conductivity of the plastics of which the strip is formed;

Kg is the heat conductivity of the gas to be passed through the matrix;

S is the spacing between the strip layers, and

t is the thickness of the strip.

4. A matrix as claimed in claim 3 wherein the parameter

$$\frac{KsS}{Kgt}$$

is between about 10 and 100.

5. A matrix as claimed in claim 2, 3 or 4 wherein the parameter KgL^2 is about 500 or more where:

Kg is the heat conductivity of the gas to be passed through the matrix.

6. A matrix as claimed in claim 2 wherein the parameter

$$\frac{KsS}{t}$$

is about 1.4 BTU/hr.-ft.deg.F or greater, where:

Ks is the heat conductivity of the plastics of which the strip is formed;

S is the spacing between strip layers; and

t is the thickness of the strip.

7. A matrix as claimed in claim 6 wherein the parameter

$$\frac{KsS}{t}$$

is between about 0.14 and 1.4 BTU/hr.-ft.deg.F.

8. A matrix as claimed in claim 2, 6 or 7 wherein the parameter

$$\frac{L^2}{KsSt}$$

is in excess of about 7 hr.-ft.deg.F./BTU, where:
Ks is the heat conductivity of the plastic;
L is the length of the gas passages;
S is the spacing between the strips; and
t is the thickness of the strips.

9. A matrix as claimed in any one of claims 2 to 8 wherein the strip is in film form.

10. A matrix as claimed in any one of claims 2 to 9 wherein the wound plastics strip is spirally wound.

11. A matrix as claimed in any one of claims 2 to 10 wherein the strip is wound around a hub.

12. A counterflow heat regenerator matrix, formed of a strip of material around a hub, the strip having embossments formed at longitudinally spaced positions on the strip, the outer ends of the embossments at each location terminating in spaced relation to the side edges of the strip, whereby a continuous portion of the strip along the side edges is un-embossed.

13. A matrix as claimed in any one of claims 2 to 11 wherein the spacing means comprise surface projections on one or both sides of the strip.

14. A matrix as claimed in claim 13 wherein the surface projections extend transversely of the strip.

15. A matrix as claimed in claim 14 wherein the surface projections have a length less than the width of the strip.

16. A matrix as claimed in claim 15 wherein the surface projections comprise embossments.

17. A matrix as claimed in claim 16 wherein the outer ends of the embossments terminate in spaced relation to the edges of the strip.

18. A matrix as claimed in claim 12 or 17 wherein each embossment comprises two or more separate transversely spaced embossments separated by un-embossed portions.

19. A matrix as claimed in any one of claims 2 to 18 wherein the spacing means are spaced apart longitudinally of the strip a distance at least about 20 times the height of the spacing means.

20. A matrix as claimed in any one of claims 2 to 19 wherein the width of the matrix is between about .25 and 1.0 inches, the thickness of the strip is between about .001 and .01 inches, the space between the strip layers is between about .007 and .02 inches, and the thickness of the strip is not greater than the space between the strip layers.

21. A matrix as claimed in any preceding claim wherein the plastics has a modulus of elasticity of 150,000 p.s.i. or greater.

22. A matrix as claimed in any preceding claim wherein the plastics is polystyrene, polycarbonate, polyvinyl chloride or polyethylene terephthalate polyester.

23. A strip for making a heat regenerator matrix substantially as herein described with reference to Figure 1, Figure 2 or Figure 7 of the accompanying drawings.

24. A heat regenerator matrix substantially as herein described with reference to Figures 1 to 6, Figures 7 and 8 or Figures 9 and 10 of the accompanying drawings.

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